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Structure, electrical resistivity, oxidation and corrosion behavior of tin-lead eutectic alloy

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Abstract: The structure, electrical resistivity, oxidation and corrosion behaviors of the eutectic Sn-Pb alloy have been studied and analyzed using X-ray, Ohm's law circuit, thermal gravimetric analysis (TGA) and chemical weight loss method, respectively. The results showed that, the alloy exhibited two phase mixtures of α-Pb and β-Sn. The I-V characteristic curve of this alloy was described and the room temperature electrical resistivity was calculated and found to be 24.6 ± 1 μΩ.cm. Also, the variation of electrical resistivity with temperature was described in the range from the room temperature to 91 ºC and the temperature coefficient of resistivity (TCR) was also calculated. Furthermore, it was found that, the alloy exhibited a good oxidation and corrosion resistance for long run.

Keywords: Sn-Pb Eutectic Alloy, Oxidation and Corrosion Behavior, Electrical Resistivity

1. Introduction

Soldering process is one of the most important methods used for joining electronic components in electronic devices. That is because the advances in transistors, diodes and specially integrated circuits have been revolutionized in electronic manufacturing throughout the world. These components are of very little values as individual components and to be used, they must be electrically connected to each other and mechanically to the printed circuit board by the so-called solders. They based on the tin-lead alloys due to their unique combination of material properties and low cost [1-5]. The popularity of these alloys is due to their relatively low melting point, aggressive bonding characteristics, good wicking tendencies and good electrical continuity. The reason is, lead in Sn-Pb alloys provides many technical advantages; reduces the surface tension of pure tin, prevents the transformation of white tin to gray tin and serves as a solvent element. The eutectic lead-tin alloy is the most alloy composition used in electronic application. So the present paper aims to identify the structure, electrical properties, corrosion and oxidation behaviors of the eutectic tin-lead solder alloy, which is still in use until today although there are many regulations and legislations tend to prevent the use of lead due to adverse health effects.

2. Experimental Procedures

The alloy sample used in this study is the traditional lead-tin eutectic alloy. It has a long wire form of average diameter 1 mm. X-ray diffraction technique with Cu-K_α radiation was used to identify the structure of this alloy. Electrical resistivity values were calculated from the I-V curve using a simple circuit of Ohm's law. Furthermore, the circuit was connected to a heater plate to determine the behavior of the alloy with temperature. Also, the temperature coefficient of resistivity was calculated. Thermal gravimetric analysis (TGA) in the presence of Oxygen atmosphere at 120 ºC was studied and analyzed during 2.5 hrs., of exposure. Also, corrosion behavior of the alloy sample in a chemical solution of 2 Mol HCl versus exposure time in the range of 0 to 50 minutes in steps of 10 min was done using the weight loss method [6].

3. Results and Discussion

3.1. X-Ray Diffraction

Fig.(3.1) shows the XRD pattern of the Sn-Pb eutectic alloy. It shows that the pattern contains peaks due to solid solution of Sn in face center cubic Pb and a solid solution of little Pb in the body center tetragonal Sn. The binary equilibrium phase diagram of Sn-Pb [7] indicates that, the solubility limit of Sn in Pb is 19.1wt.% and the solubility limit of Pb in Sn is 2.5wt.%. Details of these phases are presented in table (3.1). It was found that, the lattice parameter, a of Pb solid solution is equal to 4.935 Å, which is a lower value than that of pure Pb (4.949 Å). This reduction could be attributed to the solubility of Sn of lower atomic radius than that of Pb matrix phase in Pb solid phase, which may cause a contraction of the unit cell of Pb phase. Furthermore, it was noticed that the main peak of the matrix is the β-Sn (111) and has the biggest lattice spacing in the lattice. It displays diffraction line broadening. The breadth of the real line profile, b, is inversely proportional to the size Z, of coherently diffraction domains in direction perpendicular to the diffraction planes according to Scherer's equation; $Z = 0.89\lambda / b\cos\theta$.

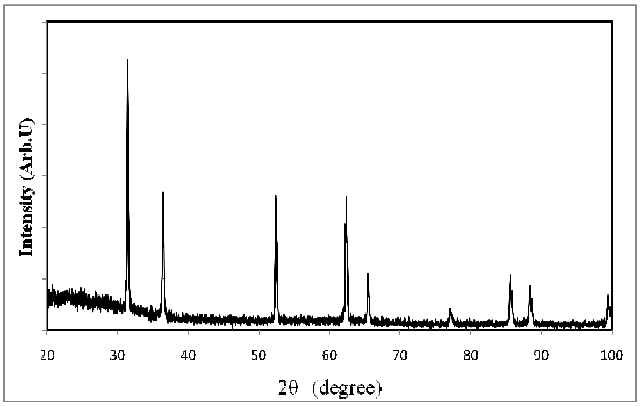

Fig. (3.1). *XRD pattern of the Sn-Pb eutectic alloy.*

Table (3.1). *Details of the phases presented in the Sn-Pb eutectic alloy.*

2θ (Degree)	d-spacing Å	I / I_0	hkl	Phase
31.47	2.843	100	111	Pb
36.42	2.467	49.02	200	Pb
52.42	1.750	51.95	220	Pb
62.39	1.490	46.19	112	Sn
65.39	1.427	16.28	222	Pb
77.14	1.236	5.15	400	Pb
85.58	1.130	16.53	331	Pb
88.32	1.107	15.37	420	Pb
99.45	1.010	9.96	431	Sn

3.2. Oxidation Behavior

The oxidation resistance of the alloys was determined by the thermal gravimetric analysis (TGA). It is convenient to know the behavior of solder alloys at higher temperature with the oxygen. The sample was cleaned and degreased by etchant and acetone, respectively. Afterwards, it was placed in an Al_2O_3 crucible and heated at 150 ºC in N_2 atmosphere for 1 h to prevent re-oxidation of the sample. Then the N2 is turned off and heated the sample again at 120 ºC for a certain time. Fig.(3.2) shows the variation of the weight against aging time of the Sn-Pb eutectic alloy. It shows a rapid increase of the weight in the first 20 minutes, followed by a nearly constant weight with time. This increase can be attributed to the formation of some oxide layers on the surface of the alloy sample. From this figure, the rate of the weight gain of the Sn-Pb eutectic alloy was calculated and the result is illustrated in Fig.(3.3). It demonstrated that, the rate of the weight gain increases rapidly with aging time in the first 20 minutes, followed by a steeper range of decreasing the rate. This decrease could be attributed to the precipitation of some oxides layer that may act as protective layers and prevent further oxidation.

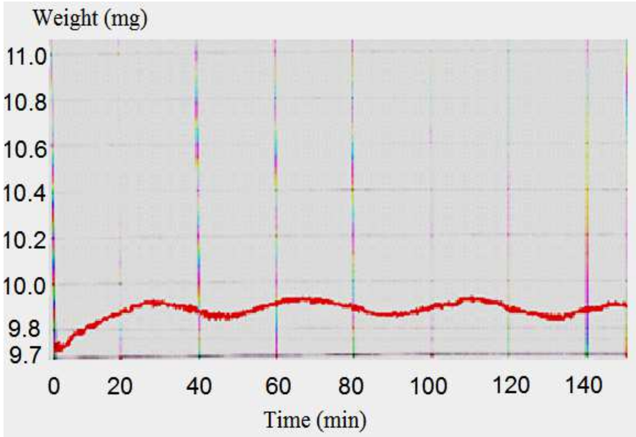

Fig. (3.2). *Weight (mg) of the Sn-Pb eutectic alloy versus time.*

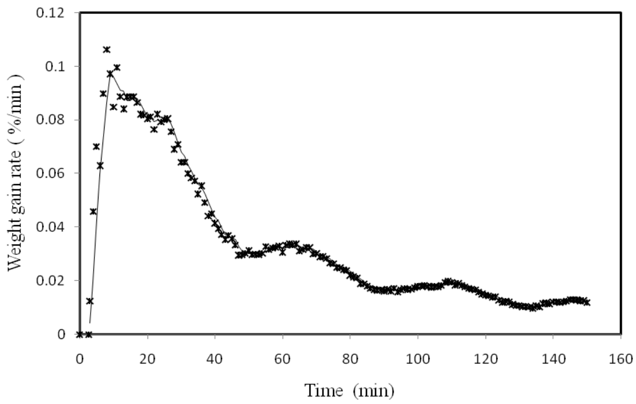

Fig. (3.3). *Weight gain rate % of the Sn-Pb eutectic alloy versus time.*

3.3. Electrical Resistivity Measurements

In microelectronic devices, the solder serves as an electrical interconnection; i.e., all currents going into and out the silicon in the device must pass through the solder connection. Therefore, in most microelectronic applications, the resistivity of the solder interconnect should be so low that its value does not affect on the functionality of the circuit. Fig.(3.4) shows the current-voltage relation of the Sn-Pb eutectic alloy. It shows a linear relation indicating that, the alloy is Ohmic material. The electrical resistivity of the alloy sample was first calculated many times and the average value was taken into account. It was found that, the electrical resistivity is equal to 24.6 ± 1 μΩ.cm, which is a high value when compared with a wide range of lead-free solders [8-15]. After that, the circuit was connected to a heater plate and recorded the value of the voltage versus temperature in the range of the room temperature to 91 ºC then calculating the electrical resistance with temperatures as illustrated in Fig.(3.5). In addition, the electrical resistivity was also calculated in this range of temperatures and the result is illustrated in Fig.(3.6). It shows a linear increase of resistivity with temperature. This increase could be attributed to the disturbances in the lattice order due to the thermal vibration which may cause scattering of conduction electrons according to Matthiessen's rule, according to the following formula;

$$\rho_{(T)} = \rho_0 + \rho_{ph}$$

Where, ρ_{ph} is the resistivity due to thermal phonons and ρ_0 is the resistivity at room temperature. Also, the temperature coefficient of resistivity (TCR), denoted by the symbol α, was calculated from the figure using the relation $\rho_{(T)} = \rho_0[1+\alpha(T-T_0)]$. It was found to be 0.011 C^{-1}. Ideally, it should be as small as possible around this temperature which is the working temperature for most electronic devices.

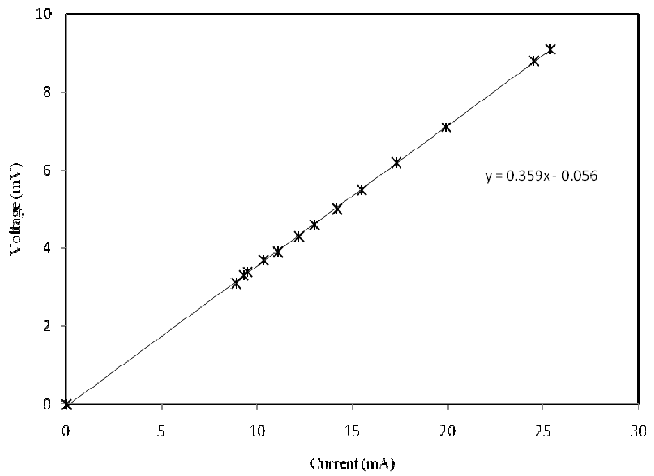

Fig. (3.4). *Voltage versus current for the Sn-Pb eutectic alloy.*

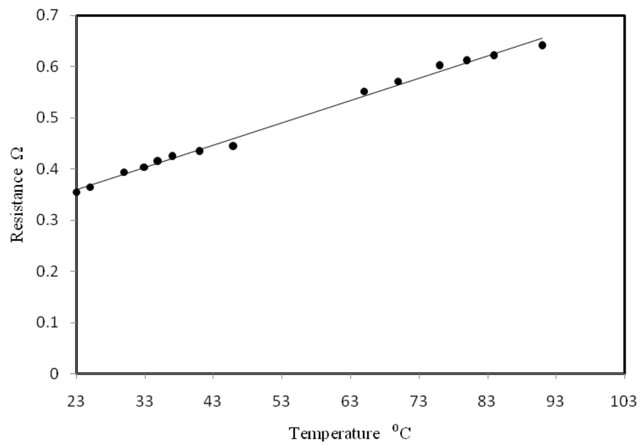

Fig. (3.5). *Resistance of the Sn-Pb eutectic alloy versus temperature.*

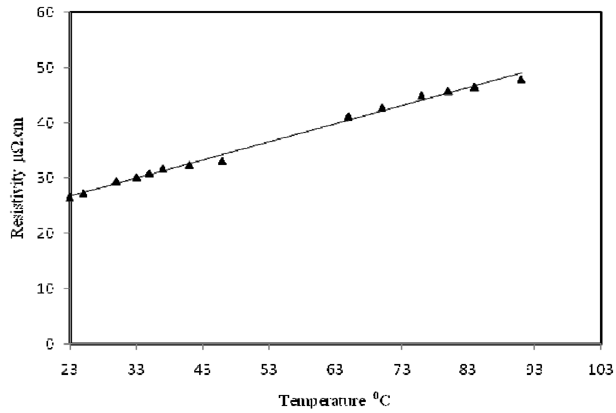

Fig. (3.6). *Electrical resistivity versus temperature of the Sn-Pb eutectic alloy.*

3.4. Corrosion Behavior

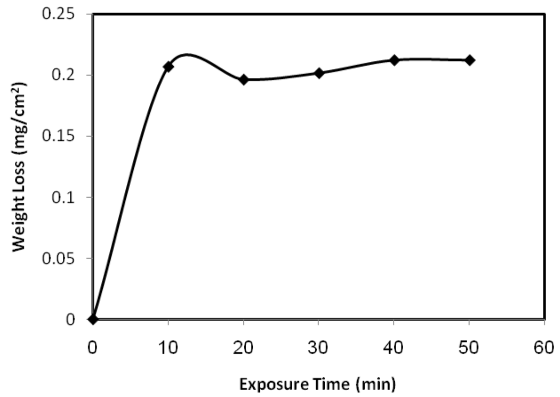

Fig. (3.7). *Weight loss of the Sn-Pb eutectic alloy versus exposure time.*

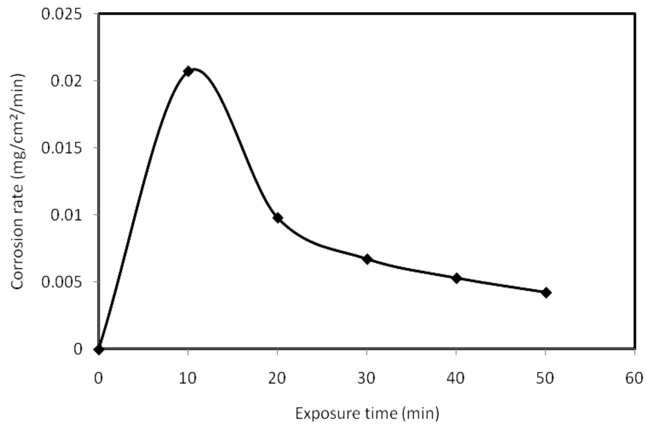

Fig. (3.8). *Corrosion rate of Sn-Pb eutectic alloy versus exposure time.*

Corrosion resistance is an important property in the discussion of metals and alloys. It is a property of a material that describes its ability to withstand attacks from atmospheric, chemical, or electrochemical conditions. Corrosion behavior of metals in an aqueous environment is characterized by the extent to which it dissolves in the solution. This can be quantified using the weight loss method using the relationship; $W_0 = W_B - W_A$, where, W_0; weight loss in the test solution, W_B; weight before exposure and W_A; weight after exposure in the chemical solution [16]. Fig.(3.7) shows the variation of the weight loss (mg/cm^2) of the Sn-Pb eutectic alloy sample in a solution of 2 Mol HCl versus exposure time in the range of 0 to 50 minutes. It shows that, the weight loss increases rapidly through the first 10 minutes followed by a nearly constant loss with increasing the exposure time. From this figure, corrosion rate was calculated and the results are illustrated in Fig.(3.8). It shows a rapid increase of the rate in the first 10 minutes followed by continuous decrease. The stability of this alloy after the first 10 minutes may be due to the formation of a protective layer of mixed oxides of Pb and Sn on the surface of the alloy which may prevent the continuous attack of corrosive ions. This reveals the stability of the alloy against the medium for long run. By surface's examination, it was noticed that it hasn't any type of localized corrosion which means only a general corrosion occurred.

4. Conclusions

The structure, electrical resistivity, oxidation and corrosion behavior of the Sn-Pb eutectic alloy has been determined in this paper. The results can be summarized in the following notes:

a The alloy exhibited two phase mixtures, cubic lead as a solid solution and tetragonal tin. The lattice parameter, a of Pb was calculated and found to be 4.935 Å, which is a smaller value compared with that of pure Pb.

b The alloy exhibited Ohmic behavior and has electrical resistivity 24.6 μΩ.cm at room temperature.

c The resistivity increased linearly with temperature and the temperature coefficient of resistivity was calculated and found to be $11x\ 10^{-3}\ C^{-1}$.

d Oxidation behavior of the Sn-Pb eutectic alloy was described through the weight gain with time during the TGA test. Rate of the weight gain was found to be decreased with increasing aging time after the first 20 minutes due to the formation of oxide layer which may act as a protective layer and prevent further oxidation.

e The alloy exhibited good corrosion resistance for long run.

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